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Observations of Transverse and Parallel Acceleration of Terrestrial Ions at High Latitudes

H. L. Collin, E. G. Shelley, A. G. Ghielmetti, R. D. Sharp

Lockheed Palo Alto Research Laboratory,

Palo Alto, CA, 94304

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ABSTRACT

Previous studies of upflowing ions indicate that ion beams acquire their energy by a process which results in the heavier ions gaining additional transverse energy. Additional data from S3-3 is presented which suggest that ion beams are the result of a two step acceleration process in which ion conics formed at lower altitudes are then accelerated through a potential drop. In regions below such upward directed potential drops, and presumably upward currents, the original ion conics are generated by a mechanism which provides more energy to heavier ions while outside these regions ion conics are generated by a mass independent mechanism.

INTRODUCTION

The Lockheed ion mass spectrometer on the S3-3 satellite has provided numerous observations of upward flowing terrestrial ions in the energy range 0.5 - 16 keV. These have been observed in the altitude range of 2000 km to 8000 km over the auroral regions. H^+ and O^+ are the most common species with He^+ occurring occasionally [Ghielmetti et al., 1978]. Ions have been observed which have undergone acceleration primarily transverse to the geomagnetic field direction (ion conics) [Sharp et al., 1977] and primarily parallel to the field direction (ion beams) [Shelley et al., 1976].

The ion conics indicate the dominance of a transverse acceleration process. They typically have falling energy spectra [Ungstrup et al., 1979] and are most commonly seen at energies below 500eV, the threshold of the ion mass spectrometer [Gorney et al., 1981]. They are frequently observed by S3-3 at altitudes between 2000 and 8000km. In contrast the ion beams rarely occur below 5000km and typically have distribution functions which are field aligned and are peaked at energies of a few keV [Shelley et al., 1976]. Associated with the ion beams are signatures in the electron distribution functions which indicate the existence of potential drops below, and sometimes above, the satellite.

These observations suggest that ion beams acquire their energy by falling through the potential drop. However, such an explanation is too simple. The O^+ beams generally have more energy than the H^+ beams and are less closely field aligned than the H^+ [Collin et al., 1981]. This suggests that beams have not only been accelerated parallel to the field direction, but have also been accelerated transversely, and that the transverse acceleration process was mass dependent.

One explanation of the beams' transverse component of energy is that conics from lower altitudes were accelerated through a potential drop to form the beams [Chiu et al., 1983] and that the original conics had been produced by an acceleration process which accelerated heavy ions more strongly.

OBSERVATIONS AND INTERPRETATION

The magnitudes of the potential drops below the satellite can be determined by measurements of the widening of the electrons' loss-cones as has been done by Mizera and Fennell [1977] and others. When the energies of the ion beams and the corresponding potential drops are compared they show good statistical correlation (Figure 1). However, the energy of the H^+ tends to be slightly less than that corresponding to the potential drop, whereas the energy of the O^+ tends to be higher. This is consistent with the heavier O^+ having acquired additional energy.

The energies of most of the ion conics observed by S3-3 were too low to permit the distribution functions of their constituent ion species to be characterized by the ion mass spectrometer. However, a few multi-component conics were energetic enough to be examined in detail [Collin and Johnson, 1985]. One of these events was observed at an altitude of 3780km over the evening sector auroral zone, Figure 2 and Figures 3a and 3d. It was composed of H^+ and He^+ and showed marked mass dependent energy differences. While the H^+ was very soft and not detectable above 1.5 keV, the He^+ was much harder with substantial fluxes throughout the range of the spectrometer, 0.5 - 16 keV. During the four spins in which the ion conics were observed the associated electron distributions in the highest energy spectrometer, 7.3 - 24 keV, show minima at pitch angles of 90 deg. This indicates that these electrons have been accelerated through a potential drop, Φ, not far above the satellite [Kaufmann et al. 1976]. The 90 deg minima can also be seen in the 1.6 - 5.0 keV spectrometer, but are much less pronounced. This implies that most of the electrons in this energy range are approximately isotropic, probably secondaries trapped below the potential drop, and that only those near the upper end of the range have been accelerated down thorough the potential drop. Since only the accelerated electrons will exhibit the 90 deg minima $e\Phi$ is probably close to the upper energy limit, 5.0keV.

In order to determine what S3-3 would have seen above the potential drop the observed conic distributions were mapped through 5kV and through a change in B corresponding to moving from 3780km to 8000 km in a process analogous to that used by Klumpar et al. [1984]. No attempt was made to simulate the possible effects of any diffusive process. The resulting distributions, Figures 3b and 3e, were more energetic and the pitch angle widths of the conics were much reduced and are somewhat energy dependent, similar to the distributions described by Klumpar et al. [1984] and Ghielmetti et al. [1986]. The ion mass spectrometer's pitch angle resolution is about 15 deg and cannot resolve the details of such narrow distributions. When the accelerated conic distributions were sampled at the resolution of the ion mass spectrometer the distributions appeared more beam-like, Figures 3c and 3f. On the basis of these distributions, the mean energy of He^+ is 10.5keV and of the H^+ 6.8keV, E_{He}/E_H ~1.5. The pitch-angle width of the He^+, 22 deg is somewhat greater than that of the H^+, 18 deg. These relations are comparable to the statistical relationships of the observed ion beams, Collin et al. [1981] found E_O/E_H ~1.7 and mean pitch angle widths of H^+ of 15 deg and of O^+ 22 deg. This correspondence lends support to the two stage acceleration model.

Five other conics permitted detailed examination by the ion mass spectrometer. These were all composed of H^+ and O^+. In no case was there evidence of significant difference between the energies of the components. If accelerated through a potential drop, these conics would have resulted in beams whose components had the same energy and pitch angle. However, in none of these cases did the electrons show evidence of potential drops above the satellite at the time the conics were observed, although in some cases there was evidence of potential drops in adjacent regions.

None of the other conics observed by the ion mass spectrometer were suitable for detailed study, but 34 cases were found where the energies and intensities were sufficient to give a rough indication of the relative hardness of the energy spectra of the ion species comprising the conics. In 10 of these cases (29%) the electrons indicated a potential drop above the satellite. This shows that although only a single event could be studied in detail, the association of conics and potential drops is not rare. In 9 of these cases the higher mass ion was the more energetic. In the remaining cases, in which there was no evidence of a potential drop, there was only 1 case in which the higher mass ion was more energetic.

The available data are perhaps too limited to draw firm conclusions, but they do suggest that in regions below upward directed potential drops ion conics are generated by mechanisms which provide more energy to heavier ions and that outside these regions the conics are generated by a mechanism which is independent of mass. The possibility that more than one mechanism may be responsible for the production of ion conics has been discussed previously by Cattell [1984] who pointed out that several of the suggested mechanisms have spatial distributions which are different from those of conics and so could not account for all conics.

CONCLUSIONS

Previous statistical results from S3-3 indicated that the energy of ion beams is the result of a process, or processes, which not only gives the ions parallel energy, but which results in the heavier ions gaining a larger proportion of transverse energy. The present study provides some limited evidence which suggests that the ion beams are produced by a two step acceleration process in which ion conics are first formed at lower altitudes and are afterwards accelerated upward through a potential drop. In the regions below such potential drops, and presumably upward currents, the original ion conics are generated by a mechanism which provides more energy to heavier ions while outside these regions ion conics may be generated by a mass independent mechanism.

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Figure Captions

1. The potential drop, Φ, below the satellite as determined from electron loss-cone measurements and the corresponding ion mean energies, E_I. The dashed lines indicate $E_I = e\Phi$.

2. Survey plot of data from the ion mass spectrometers and electron spectrometers. The abscissa indicates the universal time, altitude, invariant latitude and magnetic local time at which the data were acquired. Panel 1 shows the mass spectrometers' sequence of energy steps. Panels 2-5 show the counts of ions summed once per second from selected channels from all three ion mass spectrometers. Panel 6 indicates the pitch angle of the look direction of all the spectrometers and panels 7-10 display the counts per 0.5 s for the electron spectrometers. The broken lines indicate the satellite spins during which H^+ and He^+ conics were seen.

3. Contour plots of the common logarithm of the velocity space density of H^+ and He^+. The dots indicate the locations of the data points. Panels a and d correspond to the observed conics which are displayed in Figure 2. Panels b and e show these distributions after passing through a potential drop and into a region of reduced <u>B</u>. Panels c and f show how these modified distributions would appear when viewed with 15 deg pitch angle resolution.

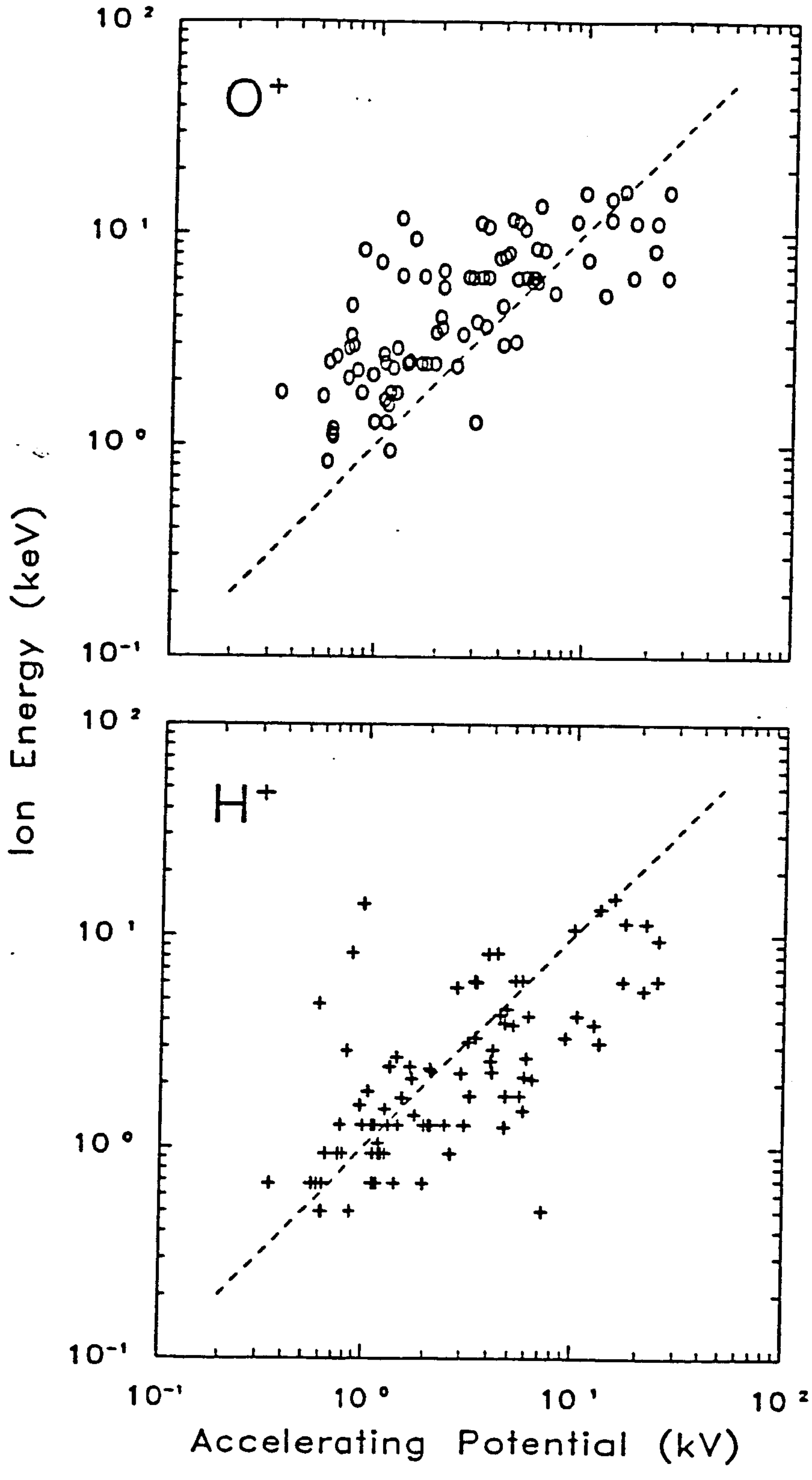


Fig 1

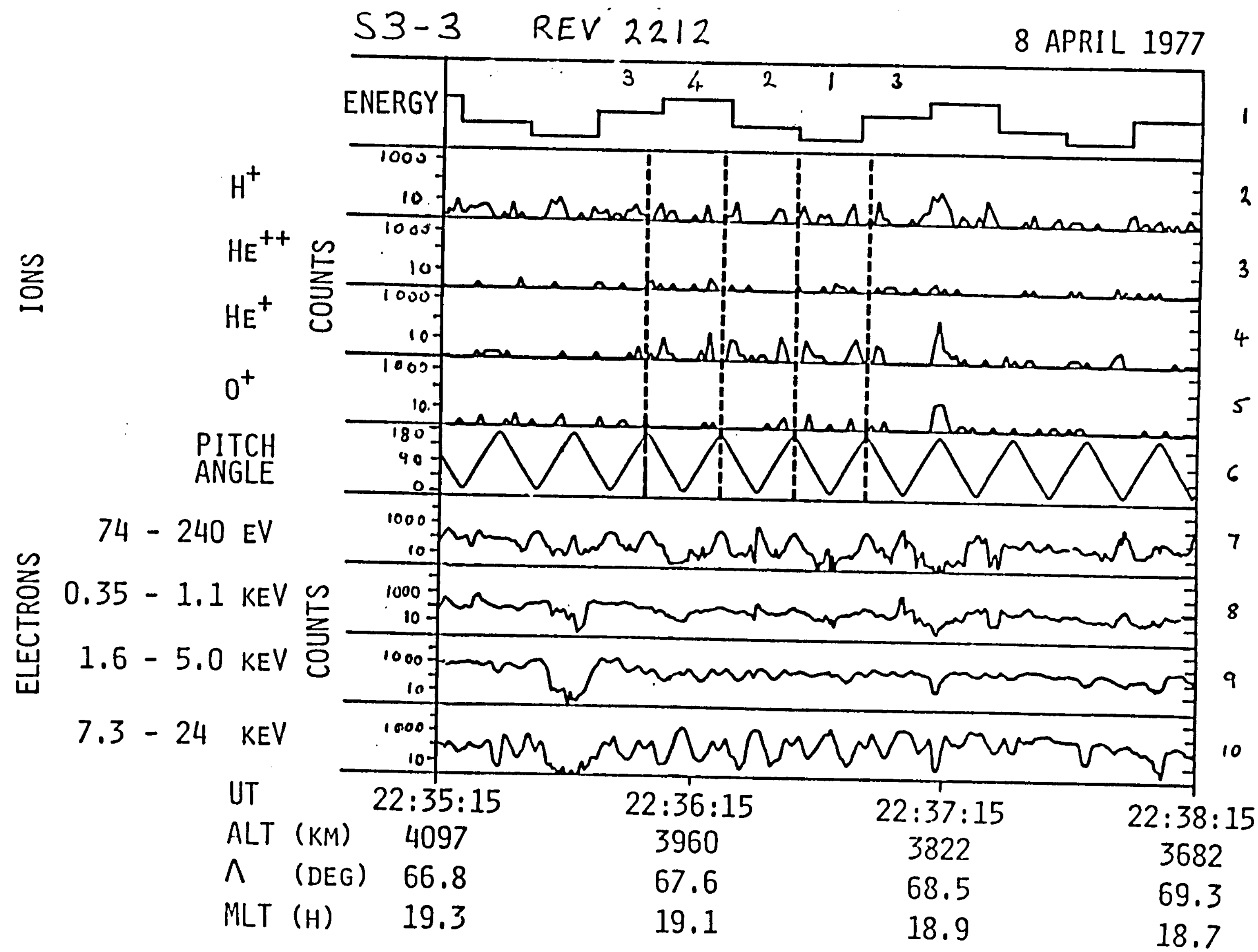
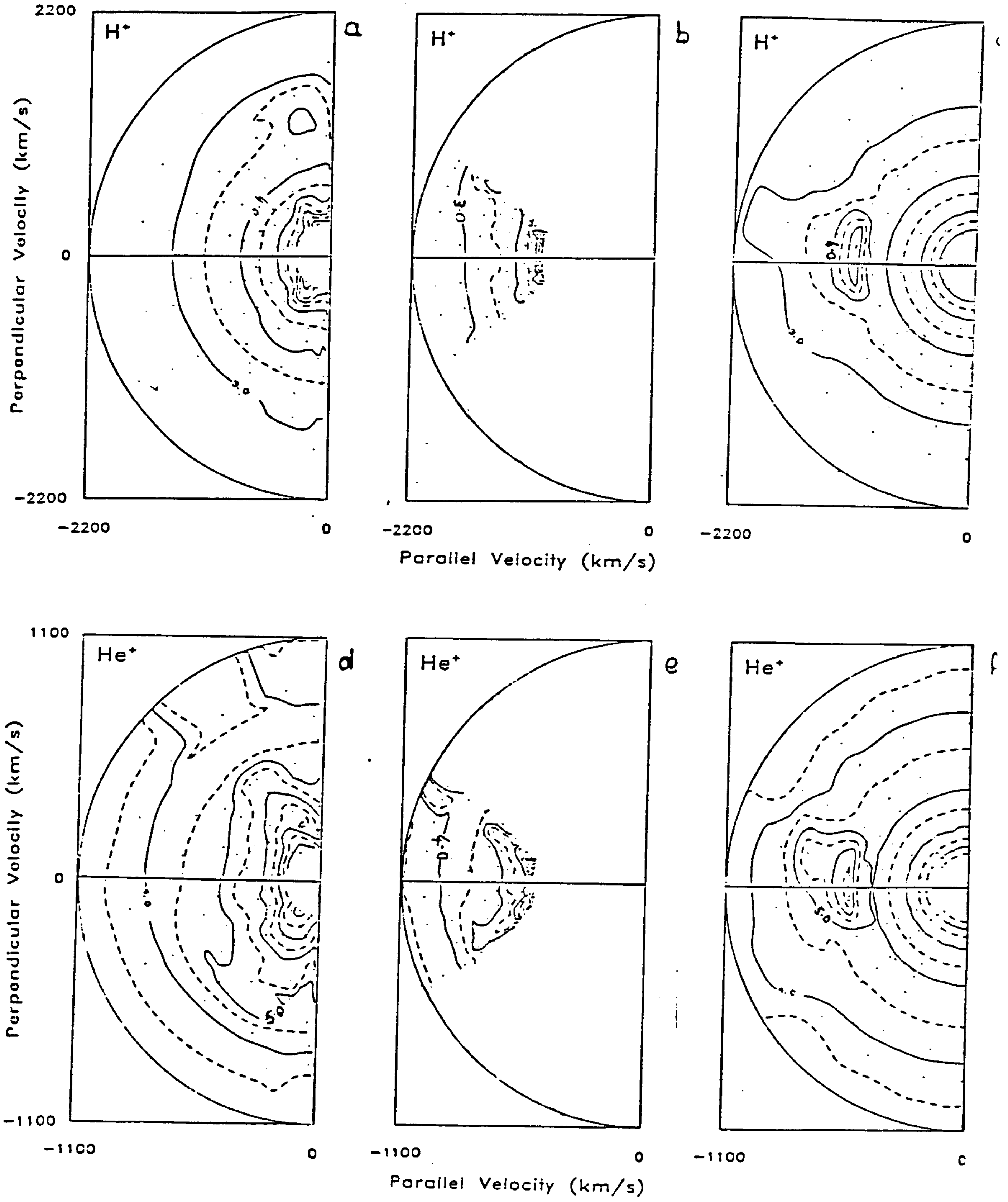

S3-3 REV 2212
8 APRIL 1977
3 4 2 1 3
ENERGY
IONS
H+
HE++
HE+
O+
COUNTS
PITCH ANGLE
180
90
0
1000
10
ELECTRONS
74 - 240 EV
0.35 - 1.1 KEV
1.6 - 5.0 KEV
7.3 - 24 KEV
COUNTS
1
2
3
4
5
6
7
8
9
10
UT 22:35:15 22:36:15 22:37:15 22:38:15
ALT (KM) 4097 3960 3822 3682
Λ (DEG) 66.8 67.6 68.5 69.3
MLT (H) 19.3 19.1 18.9 18.7

Fig 2



2200
H⁺
a
H⁺
b
H⁺
0
-2200
-2200
0
-2200
0
-2200
0
Parallel Velocity (km/s)
Perpendicular Velocity (km/s)
1100
He⁺
d
He⁺
e
He⁺
f
0
-1100
-1100
0
-1100
0
-1100
c
Parallel Velocity (km/s)
Perpendicular Velocity (km/s)

Fig 3